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14. ABSTRACT
Several experiments were performed to advance the development of condensate interferometry for the purposes of inertial sensing. Key results include: 1) A novel bouncing-atom interferometer was developed which could permit sensitive measurement of gravity and accelerations without requiring a large interaction volume. 2) A small but scalable area-enclosing interferometer was demonstrated using magnetically confined atoms. 3) A new Bose-Einstein condensation apparatus was constructed with a magnetic trap design optimized for inertial

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UU	UU	UU	UU		Charles Sackett
					19b. TELEPHONE NUMBER
					434-924-6795

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Report Title

Extending the Interaction Time of Linear and Ring-Shaped Condensate Interferometers

ABSTRACT

Several experiments were performed to advance the development of condensate interferometry for the purposes of inertial sensing. Key results include: 1) A novel bouncing-atom interferometer was developed which could permit sensitive measurement of gravity and accelerations without requiring a large interaction volume. 2) A small but scalable area-enclosing interferometer was demonstrated using magnetically confined atoms. 3) A new Bose-Einstein condensation apparatus was constructed with a magnetic trap design optimized for inertial measurements.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
09/01/2011	1.00	K. J. Hughes, J. H. T. Burke, C. A. Sackett. Suspension of Atoms Using Optical Pulses, and Application to Gravimetry, Physical Review Letters, (04 2009): 150403. doi:
09/01/2011	2.00	J. H. T. Burke, C. A. Sackett. Scalable Bose-Einstein-condensate Sagnac interferometer in a linear trap, Physical Review A, (12 2009): 0. doi: 10.1103/PhysRevA.80.061603
09/01/2011	3.00	R. Leonard, C. Sackett, R. Horne. Utility of atomic kicked-rotor interferometers for precision measurements, Physical Review A, (6 2011): 0. doi: 10.1103/PhysRevA.83.063613

TOTAL: **3**

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received	Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received		Paper
09/01/2011	6.00	Robert Horne, John Burke, Jiraphat Tiamsuphat, Vanessa Leung, Cass Sackett. Design and construction of condensate interferometers for inertial navigation applications, 40th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics . 2009/05/23 00:00:00, . : ,
09/01/2011	7.00	John Burke, Cass Sackett. Implementation of a Bose Einstein condensate gyroscope, 40th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics . 2009/05/20 00:00:00, . : ,
09/01/2011	8.00	J.H.T. Burke, V. Leung, R.A. Horne, R.H. Leonard, C.A. Sackett. BEC Precision Interferometry: Towards a Measurment of the DC Polarizability of 87Rb, 41st Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics . 2010/05/26 00:00:00, . : ,
09/01/2011	9.00	Vanessa Leung, John Burke, Robert Horne, Robert Leonard, Charles Sackett. A circular dual BEC interferometer gyroscope, 41st Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics . 2010/05/25 00:00:00, . : ,
09/01/2011	10.00	R.H. Leonard, R.A. Horne, C.A. Sackett. A Dual-Condensate Interferometer for Vibration-Free Measurements, 42nd Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics . 2011/06/13 00:00:00, . : ,
09/01/2011	11.00	R.A. Horne, R.H. Leonard, C.A. Sackett. Numerical Study of an Atomic Delta Kicked Rotor Interferometer for Precision Measurements, 42nd Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics . 2011/06/14 00:00:00, . : ,

TOTAL: **6**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received   Paper

TOTAL:

Number of Manuscripts:

Books

Received   Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Jeramy Hughes	0.35	
Robert Horne	0.15	
Bob Leonard	0.10	
John Burke	0.35	
FTE Equivalent:	**0.95**	
Total Number:	**4**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Vanessa Leung	1.00
FTE Equivalent:	**1.00**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Charles Sackett	0.10	
FTE Equivalent:	**0.10**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Jiraphat Tiumsuphat	0.50	Physics
FTE Equivalent:	**0.50**	
Total Number:	**1**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 1.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 1.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 1.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 1.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME	
Jeramy Hughes	
John Burke	
Total Number:	**2**

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Statement of Problem Studied:

Atom interferometry is a measurement technique in which the wave function of an atom is split into two parts that are then spatially separated. While separate, the two parts develop different quantum phases, and when they are recombined, the phase difference can be determined. The interferometer can be configured such that the phase difference is sensitive to gravity, accelerations, and rotations of the system. Atom interferometers using atoms from an ordinary thermal distribution have been used to produce some of the most sensitive accelerometers and gyroscopes on record.

One way that this performance could be improved even further is by using a Bose-Einstein condensate (BEC), rather than a thermal gas. The atoms in a BEC share a common wave function, which make interference effects much easier to exhibit. In particular, condensate atoms can readily produce interference even while confined in a trap. The can be useful, because trapped atoms can be probed for a longer time than freely falling atoms. Also, the trap may induce the atoms to undergo more complicated motion than is easily achieved with free atoms. Another advantage of BECs is that the atoms have an exceedingly small range of velocities, which makes some types of manipulations more feasible.

Our group has been pursuing the development of BEC interferometers, and the goal of the current project was to determine ways to further improve their performance. We acheived this goal by developing new interferometer schemes and by making improvements to our apparatus.

Summary of Results:

Bouncing Interferometer - As described in Ref [1], we developed a novel atom interferometer scheme based on suspending atoms using repeated pulses from a laser beam. We start by turning off our magnetic trap and dropping a condensate. The atoms accelerate as they fall until they reach a momentum equal to half the momentum of a laser photon. We then turn on a vertically oriented standing-wave laser such that each atom absorbs one photon, causing them to recoil upwards. Under free fall, they turn around and start falling again. When they reach the appropriate velocity, we apply another laser pulse, repeating the process. We were able to keep the atoms suspended for up to 100 bounces. Using a more complicated arrangement of pulses, we successfully implemented an interferometer using the suspended atoms, in which the phase difference between two packets was sensitive to gravity.

The performance of this interferometer was limited by technical imperfections, yielding a measurement accuracy of only a several parts per million. Calculations suggest, however, that considerably better performance could be achieved. Compared to other interferometry scheme for sensing gravity, our technique offers a major advantage because the atoms do not fall a significant distance during the measurement. This substantially reduces the volume required for the measurement, and also simplifies the measurement analysis because the variation in the strength of gravity over the measurement region is much smaller.

Sagnac Interferometer - In order to measure rotations, the trajectories of the wave packets in an interferometer must enclose a non-zero area. Our previous work had used only linear interferometers, in which the enclosed area was zero. We developed a new technique in which the trapped atoms were driven to oscillate transversely in our magnetic guide, and then split with a laser beam passing along the guide axis. The resulting trajectories did enclose an area. We were not, however, able to directly measure the rotation sensitivity.

The performance of the Sagnac interferometer was limited, we believe, by fluctuations in the transverse motional amplitude. We developed an improved scheme in which the transverse excitation is provided in a more controlled way using laser manipulation. We have not yet implemented this technique, however.

Improved Linear Guide - Prior work had demonstrated that the linear interferometer configuration we normally use can be limited by the flatness of the magnetic guide in which the atoms are confined. Our original guide had an approximately harmonic axial potential providing an oscillation frequency of about 1 Hz. This limited the interaction time for our measurements to about 70 ms. We constructed a new flatter guide which reduced the axial oscillation frequency to about 0.2 Hz. With this guide, we observe interference for up to about 150 ms. However, at longer times the interferometer becomes very noisy, which we attribute to the effect of floor vibrations. We have obtained a high-performance active vibration isolation system, but have not yet tested it with the interferometer.

Dual Interferometers for Vibration Cancellation - We have also explored a second technique for dealing with vibrational noise, using dual interferometers. Here, a condensate is first split into two packets, and these packets are themselves split again. The second splitting operation forms the start of the interferometer measurement, so that two measurements are performed at once. Both interferometers use the same laser and trapping fields, so most environmental phases cancel out. A differential phase can be applied in various ways. Perhaps the most interesting application is to have the packets traversing a Sagnac interferometer path in opposite directions, so that the rotational phase is differential. This could substantially improve the performance of the Sagnac interferometer.

Cylindrical Trap - We have make substantial progress on constructing a new apparatus designed for rotation measurements. It will feature a cylindrically symmetric trap in which atom interferometers can be implemented using circular trajectories. Dual interferometers will be used to eliminate vibrational noise. The laser, vacuum, and computer control systems have all be implemented and tested. The actual trap structure is now being constructed.

Technology Transfer